SECTION 8 - CONCLUSIONS & RECOMMENDATIONS

The impact of human activities on environmental resources is inevitable but it is important to distinguish between well documented and perceived impacts. Competent determination of the impact of an activity not only requires information on the nature of the disturbance (comprehensively investigated and presented herein), but also on the background conditions pre-disturbance (of which there is scattered existing data that requires consolidating) and the subsequent response of the environment to that disturbance (of which there is little information spread world-wide and even less for UK waters, reviewed in Section 6). That is to say, anthropogenic disturbances must be put into the context of natural disturbances before assessment of significance.

Our reviews suggest that comprehensive collation of background and baseline environmental conditions is required. Furthermore, field data on the response of the environment to disturbances, in particular the biological response, is urgently required. Net sediment accretion due to re-sedimentation in itself may not be the most important issue: the ability of the benthic habitants to move away, burrow upward, outgrow or otherwise survive such increases in bed level *ie* the response of the environment to disturbance, is more important.

The information summarised in this report provides baseline measurements of the range of increased turbidity that may be generated by a aggregate dredging operation, its sources, likely extent and potential mitigation. The baseline review of likely biological impacts based on current information may subsequently be used by during the preparation of an EA for consideration in the context of the local situation. This project has not, however, attempted to determine the impact of elevated turbidity *per se*. This question is best answered on a site-specific basis in the Environmental Assessment of a specific dredging proposal. Rather this project highlights the significant differences between historical predictions and the actual behaviour of plumes generated by marine aggregate mining through comprehensive monitoring in the field. The results of this study have been shown to correlate well with similar studies recently published world-wide.

It is intended that the data reported herein be incorporated into the development of predictive modelling studies essential for management purposes. Further, the importance of plume behaviour is significant if it can be shown, or there may be reasonable grounds for concern, that the activities are having or there is the potential to have, an deleterious effect on the environment. An understanding of the physical and biological resources of the seabed is therefore a key requirement for formulating the Impact Hypothesis of the Environmental Assessment.

The throughput of sediments within the dredging system has been studied on a ‘Process’ basis. Each stage of the dredging process, (at the drag head, screening, and overspill) has been appraised. Losses from the system back to the water column have been identified. The plume processes of advection, dispersion and settlement have been investigated.

It is evident from the review of the literature that the study of commercial aggregate dredging operations and associated environmental disturbances is much more limited than similar information for other forms of dredging *but* is at the same time also developing quickly in response to greater application of responsibilities and generally heightened environmental awareness. It is further evident that a vast majority of the information available resides in unpublished, commercial reports which are largely un-proferred for peer review and subsequent discussion and dissemination amongst the wider scientific community. There is therefore, a clear need for development of authoritative, peer reviewed assessments of the impacts of the aggregate dredging operations.

We have collected and present herein a substantial dataset of field observations on the source terms for sediment plumes generated by commercial marine aggregate mining operations in the UK. The information provides fundamental support to quantifying the impact of dredging operations on the environment.

We have outlined the principal components of the marine aggregate dredging process which influence the development of sediment plumes. Methods of field investigation and monitoring are reviewed. This report recommends that further information is acquired on the source terms of sediments attributable to the reject chute for screened sand and gravel cargoes, and from vessels with different loading processes. Notwithstanding this, further information on all aspects of source terms will enhance the present database.

Combination of accurate field observations with the traditional modelling scenarios has resulted in modifications to the theory of behaviour of the developed plume directly (*see, for example,* HR Wallingford, 1995; Weiergang, 1995; Jensen, 1995; Whiteside *et al*, 1995; Pennekamp *et al*, 1996). These also concluded that traditional predictive techniques might overestimate the diffusive abilities of the dredge plume.

We recommend as Best Practice that monitoring of plumes issuing from dredging operations comprises a well designed and pertinent sampling and testing programme. We have shown there are significant productivity gains through the competent use of Continuous Backscatter Profiling techniques using acoustic Doppler profiling equipment with precise navigational control to effectively track and delimit the plume boundaries. This will significantly improve confidence in the interpretation of results as representative of the maxima and minima conditions.

We have accounted for the quantities of material disturbed at the seabed and their subsequent processing through the dredging system, quantifying the various outputs from the dredging operation, which act as inputs to the marine environment. The importance of detailed prospecting and reserve evaluation survey data in managing the cargo quality available from adjacent dredge runs, separated by only 500m, is emphasised by this work.

Amongst the many factors affecting the total quantity of sediment returned overboard during loading of a single cargo, the primary factors are the type of dredger, type of cargo and seabed geology. Aggregate dredge vessels may return sediments overboard amounting to between 0.2 and 5 times the cargo load. The size distribution of the overboard returns will be skewed, according to the cargo being loaded. Some 30% of the sediments lost overboard may actually be of cargo ‘grade’ (depending on the Customer requirements).

Development of techniques to monitor the sediment plume using acoustic Doppler current profiling equipment, herein termed *Continuous Backscatter Profiling* (CBP), has given considerable insight into the restricted magnitude of plume excursion when compared to predictive numerical models. Confidence in locating the sampling programme within the plume is promoted.

In general, the sand component of a plume (both from the reject and overspill sources) is not sampled beyond a distance greater than 300m (horizontal tidal current velocity vector = 0.35m/s) from aggregate dredgers normally operated in UK waters. This implies a net forced settling rate of 21mm/s, which agrees well with estimates of free particle settling velocity calculated from laboratory exercises. Further, the silt content of samples (<63µm) becomes indistinct from background conditions beyond approximately 500m from the dredger. This implies a forced settling rate of 12.6mm/s. Typical modelling values are of the order 0.1-1.0mm/s for silt sized particles. The importance of floc (dis)aggregation is not known. Interestingly, elevated suspended silt concentrations at distances of up to 1000m were observed for larger dredgers, such as the Geopotes XIV, which are not commonly used in UK waters.

Enhancement of sediment fall velocity is attributed to the development of intense localised density currents. These are introduced by the increased suspended solids concentrations and enhanced by the entry velocity of the sediments into the water. This concept is supported by independent overseas observations. The development of a density current for the larger sediments may be important in dragging the finer material to the seabed with it. The further process of aggregation of the fine sediments to the coarser, more quickly settling sediments is unknown. Research efforts are some way to establishing *in situ* values for the fall velocity of overspill sediments as a Density Current.

The comprehensive literature review on benthic ecological characteristics of aggregate resources provides a detailed insight into the complex two-way interactions between the benthos and seabed sediments. The population characteristics of nearshore ‘Opportunistic’ communities are such that they allow a rapid recovery of the initial community structure in deposits which are naturally subjected to high levels of catastrophic environmental disturbance. In more stable seabed conditions ‘Equilibrium Strategists’ develop a greater tolerance to environmental variations often facilitating the existence of sub-communities which would not otherwise survive in those conditions, but are characterised by a slow growth rate and long recovery time following disturbance.

Knowledge of the components which comprise the seabed community is therefore important not only to assess potential protection of communities, but also to assess likely community recovery times. By definition the sands and gravels targeted for aggregate extraction may be of community composition such that initial recovery times of 2-3 years are reasonable in circumstances of complete defaunation, with estimates of 5-10 years realistic for full recovery of the complex biological associations between the slow growing components of Equilibrium Communities characteristic of reef structures. It is likely that the recovery for partially defaunated seabeds (likely to be formed by commercial dredging operations) may be faster than that reported for completely defaunated communities. The sensitivity of the benthos to seabed stability is recently reviewed in Newell *et al*, (1998).

Our review of the impact of aggregate dredging on benthic biological resources shows large site-specific differences both in the effects of dredging itself and in the rate of recovery. Further, it must be assumed that such impacts are dependent on both the physical nature of the environment and on the biological communities resident in a particular area. Kenny & Rees (1996) note that in the highly disturbed natural environment of the Norfolk Banks in the Southern North Sea dredging may be of little long term biological significance due to the potential speed of physical and biological recovery following dredging (*c.f.* Wright, 1977). It would not be possible to apply the same results to other dissimilar areas without site specific studies. Nevertheless, the perception of recent studies is encouraging for the commercial aggregate industry and it may be possible to develop some generic guidelines.

Similarly, we have shown that it is largely inappropriate to apply the observations and results of investigations into other forms of dredging to the particular circumstances of marine aggregate mining. Specifically, marine aggregate mining targets only a limited range of geological sediments, within limited oceanographic parameters utilising a limited range of dredging plant. The marine aggregate industry is Customer driven and as such, Customer demand will keep such parameters within very little tolerance. Other forms of dredging, *i.e.* capital, maintenance and environmental clear-up, concern themselves with far wider ranging objectives, and the effects of these will require specific investigation.

The development of a benthic plume by the hydrodynamic and physical interactions of the draghead on the seabed has been firmly established by the present work. We have shown using underwater imaging, suspensate sampling from around the plume and CBP techniques that the magnitude of the draghead plume is minor in comparison with the surface plume. Contribution of the overboard discharge to the suspended load is 4-5 orders of magnitude greater than from the draghead. It is further considered that the impact of the draghead plume may be deemed negligible in relation to any surface plume effects.

Discharge of material from hopper overflow and the screening process is thus of dominant importance in the establishment of dispersion plumes from marine aggregate mining activities. The extent of the plume is dependent on (among other factors) the total quantity of sediment rejected, the particle size of the sediments and the velocity of the tidal current flow. Further, the rate and manner of discharge is important in defining the initial stages of plume descent as a density current (Dynamic Phase) and controls the quantity of material subsequently available for more conventional advection and dispersion away from the point of discharge (Passive Phase). Our work confirms that, as a general principle, the rate of deposition of material from the dispersing plume is much faster than would be assumed from conventional Gaussian diffusion models and that sedimentation is largely confined to distances of a few hundred metres from the point of discharge.

Importantly this suggests that the impact of dredging on benthic biological resources may be confined to the immediate vicinity of the dredged area, although little is known of the impact within areas worked commercially, in the surrounding deposits nor of the rate of recovery following cessation of dredging. Of particular interest is the possible impact of organic material released into the water column by the dredging processes which we surmise may account for much of the relatively large visible ‘plume’ which extends beyond the boundaries of measured suspended sediment load discernible above background conditions. The release of such material may play an important role in the well-documented enhancement of secondary production in deposits surrounding dredged areas and requires further investigation both as part of our understanding of plumes associated with marine aggregate dredging and with establishing the impact of these activities on biological food webs leading to commercially exploitable fish stocks.

This study thus provides, for the first time, detailed information on the plume characteristics from a variety of commercially operating marine aggregate mining vessels, and further investigates the physical disturbances generated at the seabed. Details of such source terms provides key data for modification of existing and development of new descriptive and predictive models of plume dispersion, and conforms well with contemporary studies of plume generation from other sources.

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